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(12) (19) (CA) **Demande-Application**

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(72) DUCELLIER, THOMAS, CA
(71) JDS UNIPHASE INC., CA

(51) Int.Cl.[7] G02B 27/10

(54) **DISPOSITIF D'ENTRELACEMENT POUR CAVITE RESONANTE GT A BIREFRINGENCE**

(54) **BIREFRINGENT GT RESONATOR INTERLEAVER**

[illegible] CARTER SMITH BEADLE
Received: 09 DEC 2002
Returned Y (N) By: JM
Date: __/__/__
Fee: MDA

Birefringent GT resonator for flat-top passive interleaver:

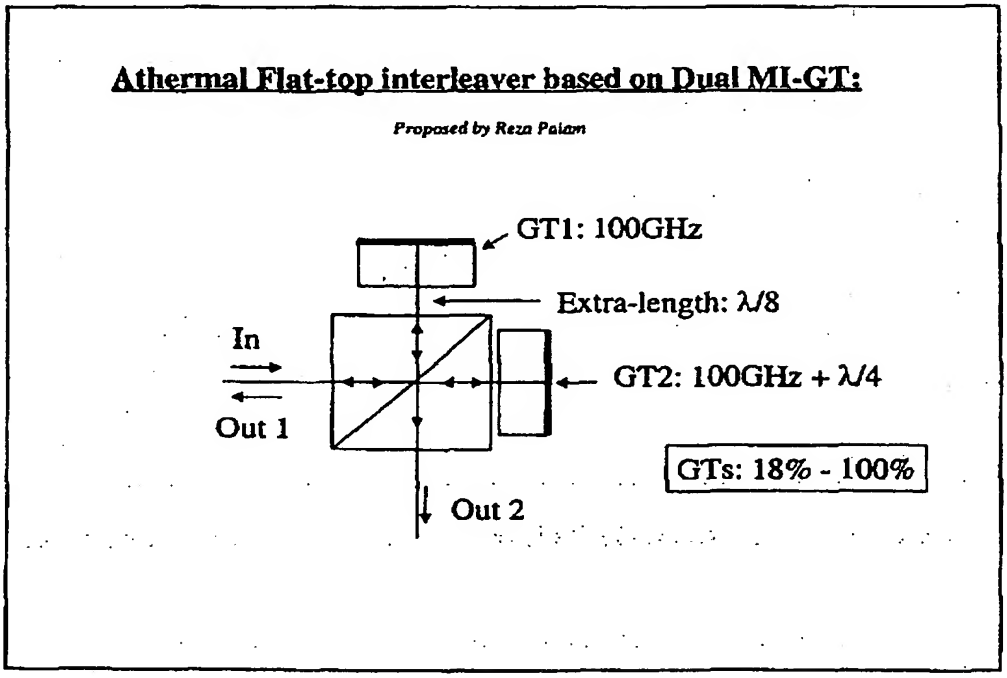
Background information:

In order to realize a flat-top interleaver that does not require temperature control, several schemes have been proposed in the past using air-spaced resonant cavities:

- Michelson + GT in one arm (ref: B.Dingel & M.Izutsu, Optics Letters, Vol.23 No.14, 1998, pp.1099-1101)
- Michelson + two GTs (ref: R.Paiam, patent application us #)
- Interference between reflected and transmitted light from a single cavity etalon with about 20% reflectivity (ref: N.Copner, patent application US#)

The present invention relates to the second option. It presents a new birefringent embodiment of this concept.

As disclosed in the above mentioned patent application, the dual-GT approach can be realized, for example, in bulk optics the following way:



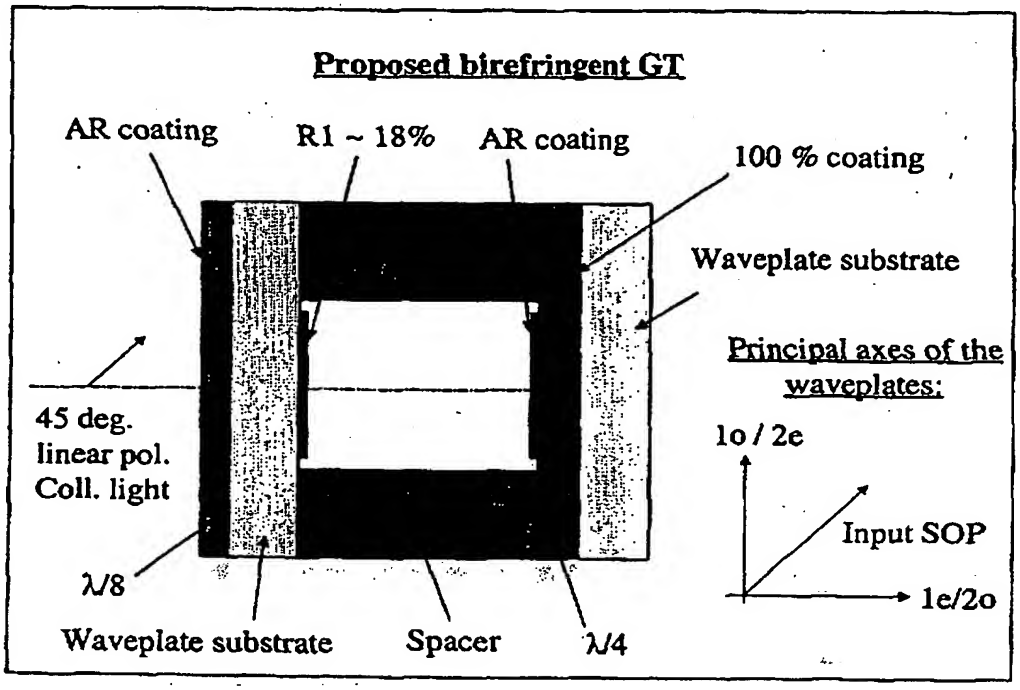
Two GTs are needed, one having a cavity longer than the other by a quarter of the wavelength (modulo a half wavelength), and there should be an arm difference in the interferometer of an eigth of the wavelength (modulo a quarter of a wavelength), the longer GT being in the shorter arm.

Different embodiments have been proposed in the past, but all require that the parts are made perfect (in other words, it is impossibl to separately tune the OPD – optical path difference between the interferometer arms – and the two FSR – free spectral range of the GTs.

The proposed invention alleviates these issues by enabling an independent and relaxed control of the parameters of the interleaver.

Description of the invention:

The following schematic shows an interleaver according to the invention, assuming linearly polarized collimated input light.

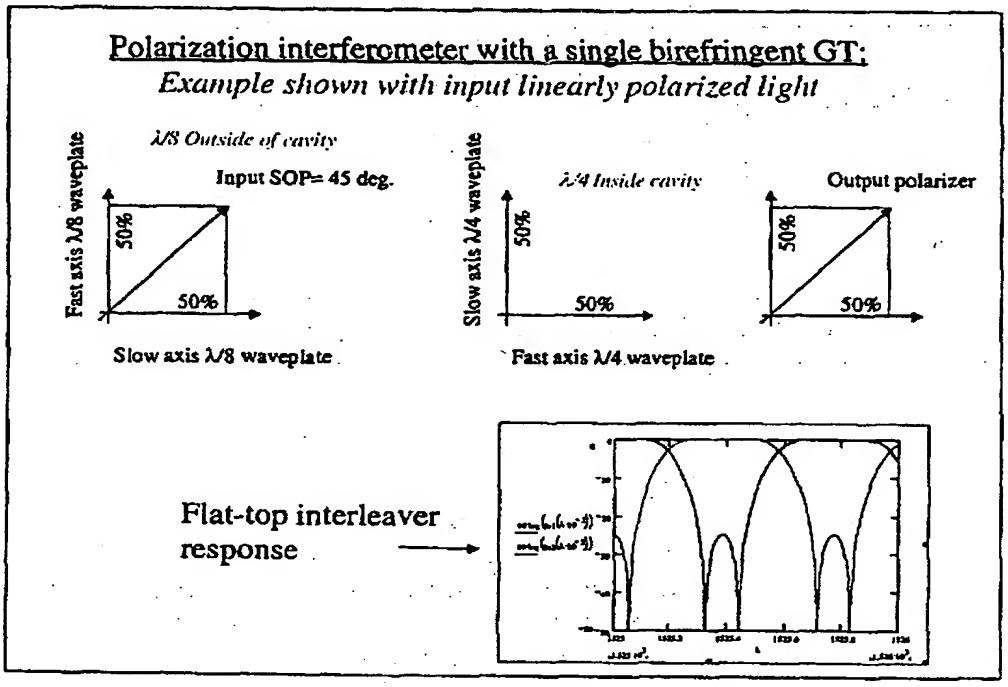


The main idea is to create the FSR and OPD difference using birefringence instead of optical length.

In this embodiment, the Michelson interferometer is replaced by a Solc interferometer (association of an input polarizer, a birefringent material, and an output polarizer). A 0^{th} order quarter wave plate is put in the cavity to create the FSR difference, and a 0^{th} order $\lambda/8$ waveplate oriented perpendicularly with respect to the $\lambda/4$ is put outside of the resonant cavity in order to create a path length difference. The two arms of the interferometers are now replaced with the two principal axis of the birefringent materials.

Since the waveplates are oriented perpendicularly with respect to each other, light polarized along ne principal axis will see a short FSR, and a longer optical path, while light polarized along the other principal axis will experience a longer FSR and no OPD.

Therefore, if the input light is linearly polarized and oriented at 45deg. with respect to the principal axis of the waveplates, it will split equally on the two perpendicular principal axis, each of those seeing a different configuration (one half of the input light will see short FSR/long path, the other half will see long FSR/short path). If an output polarizer aligned with the input light is used, the intensity versus wavelength will show the flat-top interleaving response expected from a Michelson / dual GT configuration. See following figure for more details:

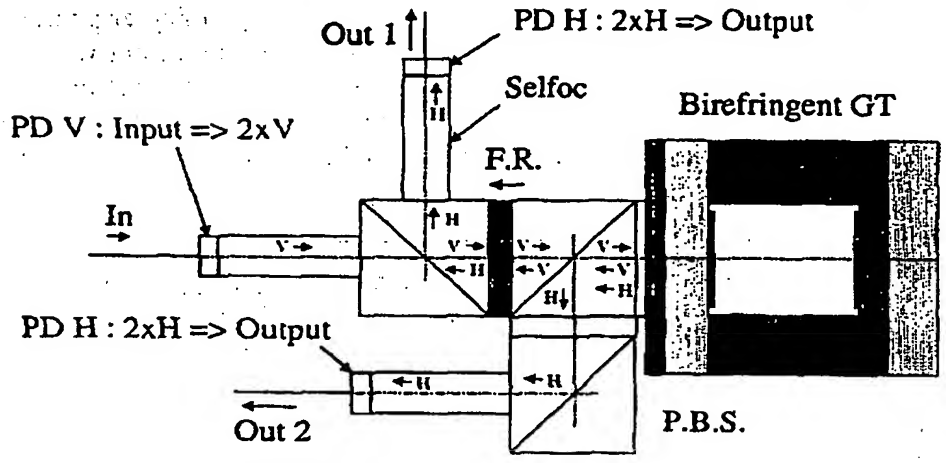


In order to use this birefringent GT with unpolarized light, a polarization dispersed front-end need to be used. For example, a rutile/waveplate assembly can be used that will convert all input light into two sub-beams of aligned linearly polarized light. The birefringent GT has then to be aligned with respect the these linearly polarized sub-beams such that the input polarization of each sub-beam is oriented at 45deg. with respect to the principal axis of the birefringent cavity.

To get a 3 (or even 4) ports device, some polarization discrimination techniques must be used. For example, a PBS will sort out between incoming state of polarization and rotated polarization. A Faraday rotator may also be used to distinguish between incoming light and outcoming non-rotated light to avoid the use of a circulator.

Without limiting the generalization of the concept, here is a preferred embodiment with all the above mentioned features:

Top view **ATHERMAL FLAT TOP INTERLEAVER (3 ports):**



F.R. = Faraday Rotator / P.B.S. = Polarization Beam Splitter
P.D. = Polarization diversity (rutile + λ/2 waveplates assembly)

Specific advantages of the proposed embodiment:
Birefringence based retardation is related to the difference of index of refraction between ordinary and extraordinary rays. This can be very small in the case of quartz. This means that a small and though very well controlled retardance can be obtained. For the case of 0^{th} order waveplate, a further advantage is their wavelength, temperature and angle insensitivity. Therefore, realizing the λ/4 FSR difference and the λ/8 OPD between arms with birefringence is easy (tolerance is at least 200 less stringent compared to polishing parts to the right thickness) and temperature insensitive.

Furthermore, since the 0^{th} order waveplate retardance is largely angle insensitive, this angle can be used to tune the FSR of the cavity, without affecting the phase relationships that need to be maintained within the interferometer.

If the GT is made of two optically contacted end plates with air in between, then the optical length of the cavity will only change with temperature as the that of the λ/4 waveplate, which is negligible for 0^{th} order waveplate (its thickness is in the order of 45 microns for quartz, so change in optical path with temperature is negligible compared to the cavity length of typically 1.5 to 3 mm).

Concluding remarks:

The concept has been experimentally verified on a bench, and works in perfect agreement with modeling. Best GT design is thought to be with 19 +/- 1% reflectivity on the front facet. Best performances are obtained with 0^{th} order waveplates oriented perpendicularly with respect to each other, but other combinations are possible, as long as the in-cavity retardance is $\lambda/4$ modulo $\lambda/2$, and the retardance outside of the cavity is $\lambda/8$ modulo $\lambda/4$. The particular case of 0^{th} order waveplates aligned with respect to each other corresponding to one of these generalized configurations.

It is though that orienting input sub-beams polarized light along the same orientation is beneficial to enable a simpler 3 ports design, but obviously the birefringent cavity will work as well if the two linearly polarized sub-beams are perpendicular to each other.

Claims

1. An optical device for interleaving or de-interleaving a central wavelengths of light corresponding to optical channels comprising:
a Gires-Tournois optical cavity including a waveplate; and,
a waveplate coupled with and outside the cavity.

2. An optical device comprising:
A GT having a $\lambda/4 \text{mod} \lambda/2$ waveplate within the cavity; and,
a $\lambda/8 \text{mod} \lambda/4$ waveplate outside and optically coupled with the cavity.

3. An optical device as defined in claim 1 or claim 2 wherein the waveplate inside the cavity and the waveplate outside the cavity have their principle axes aligned or perpendicular to each other.

4. An optical device as defined in claim 1, 2, or 3 further comprising means for providing an input beam having a predetermined polarization with respect to the polarization of the waveplates.

5. An optical device as defined in claim 3, further comprising a rutile for separating orthogonal components of an input beam into two orthogonal beams of light and means for rotating one of the two orthogonal beams to have a same polarization as the other of the two beams.

Flat-top athermal interleavers:

resonant cavities options

- 1) Michelson + GT: japanese paper

- 2) Michelson + dual GTs: Reza

- 3) Interference between light transmitted and reflected from a single etalon: Nigel

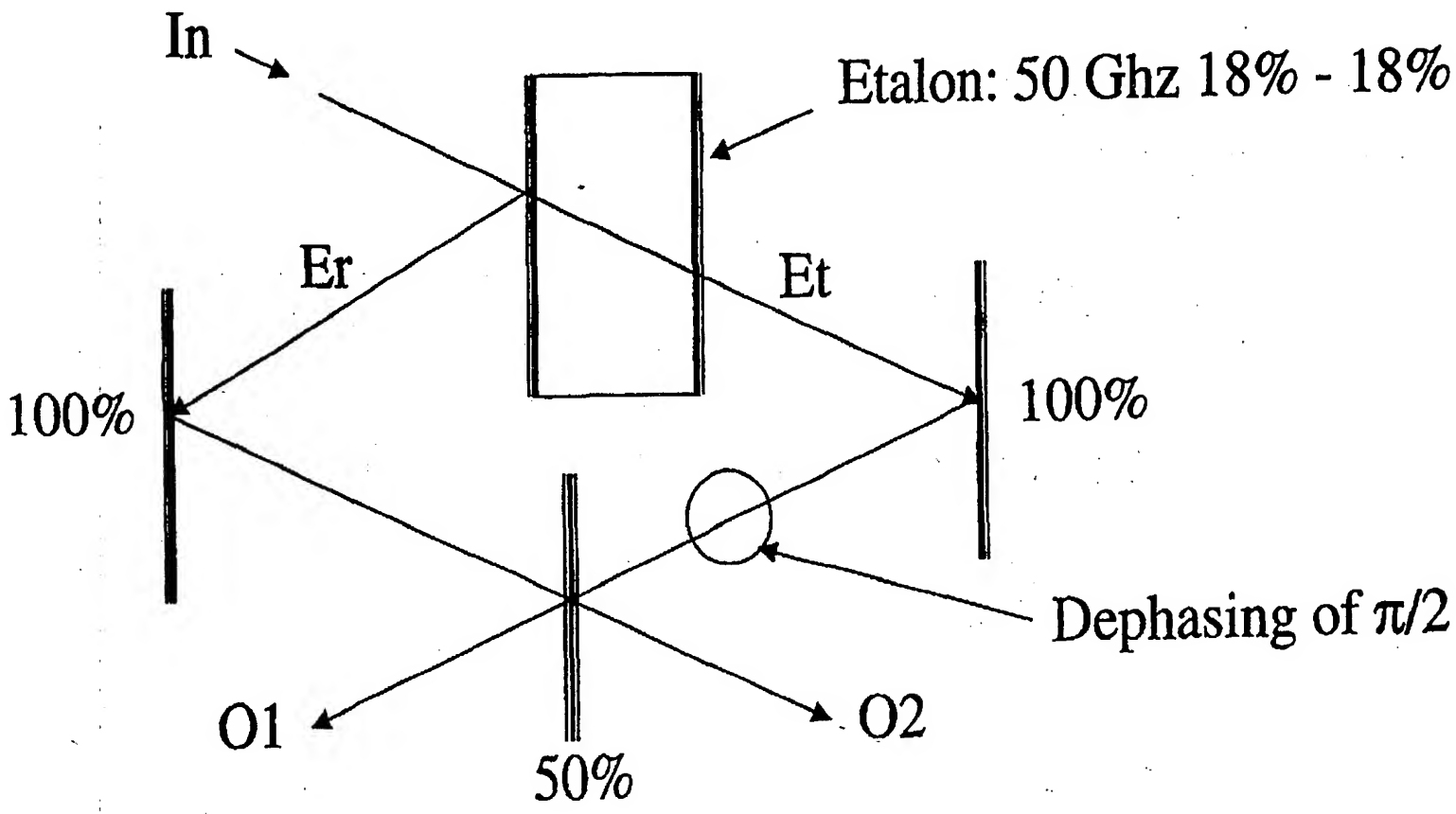
OTHER THE CURRENTLY PROPOSED EMBODIMENTS BELOW HAVE SOME LIMITATIONS OBVIATED BY THE INSTANT INVENTION

- Reza: the two GTs must be finely adjusted to 100GHz and 100GHz + $\lambda/4$ => Not doable (even not measurable !)
  there is no angle tunability (the two GTs will move)
  the cube splitter can not be made

- Nigel: the optical paths must be controlled to better than 10nm
  => the parts will need to be custom matched "by hand"
  OK for prototype, not likely to be cheap in production

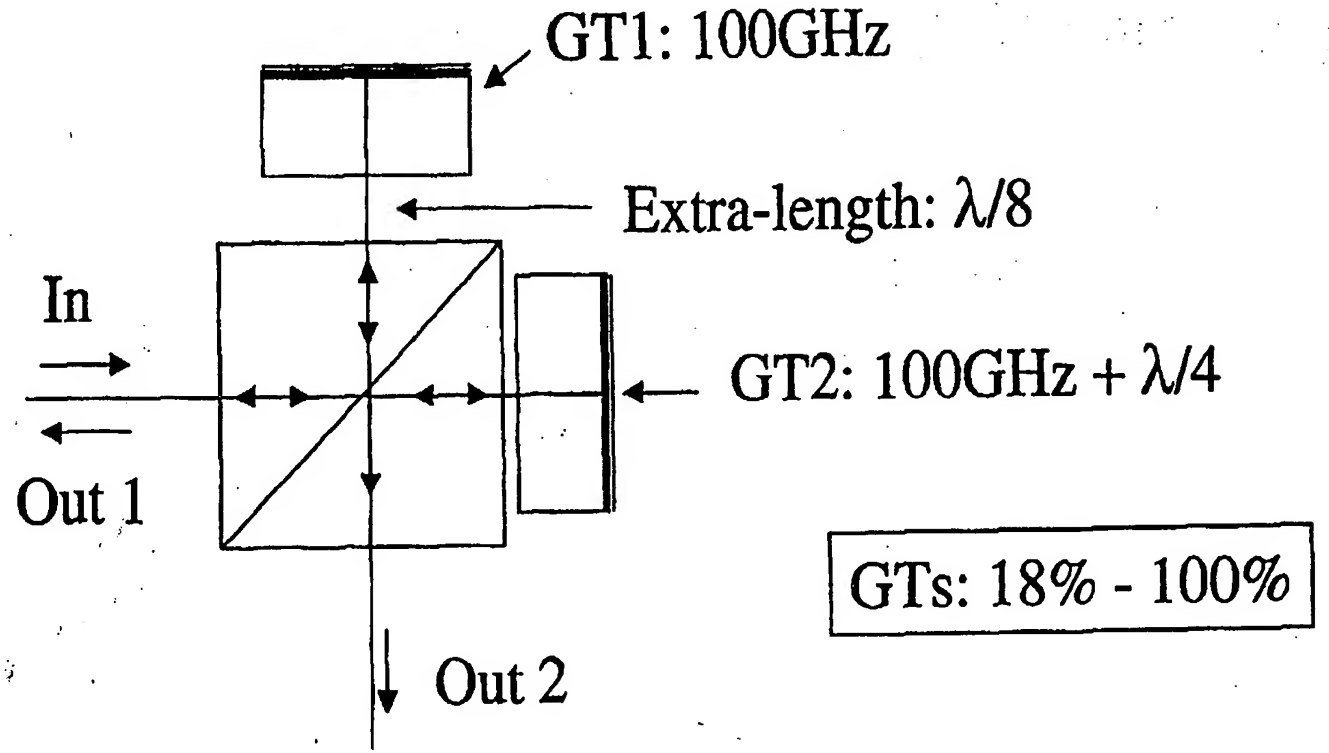
Athermal Flat-top interleaver based on a single etalon

Proposed by Nigel



Athermal Flat-top interleaver based on Dual MI-GT

Proposed by Reza Paiam

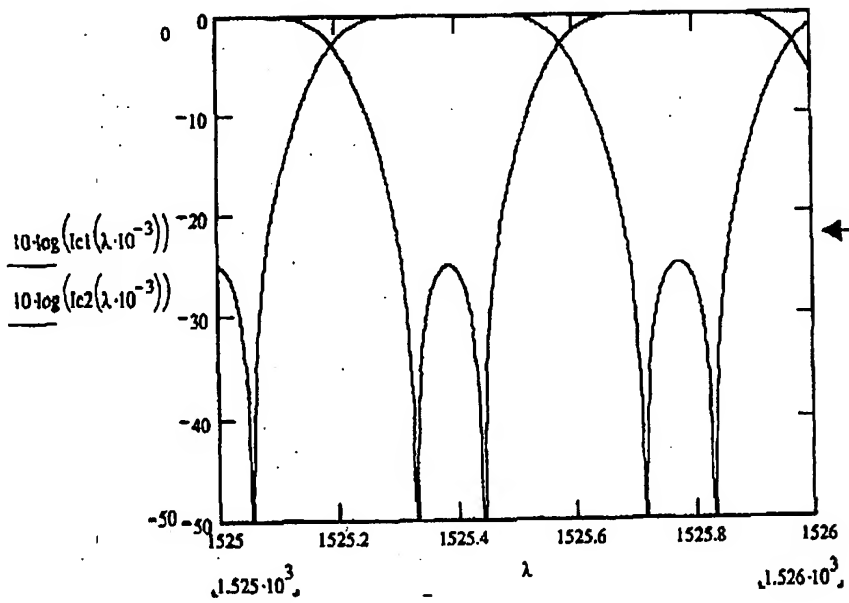


THEY ARE EXACTLY THE SAME !!!

Final equations are 100% identical

- Reza: 2 x 100GHz GTs with 2 x λ/8 between the paths
  and 2 x λ/4 in the FSR

- Nigel: 1 x 50GHz Etalon ~ virtual 2 x 100GHz GTs
  with λ/4 between the paths
  and virtual λ/2 (π) in the FSR

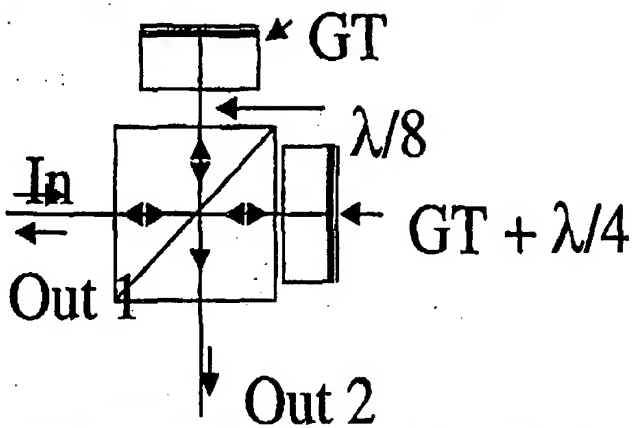


50 GHz Flat-top
Interleaver

Proposed embodiment

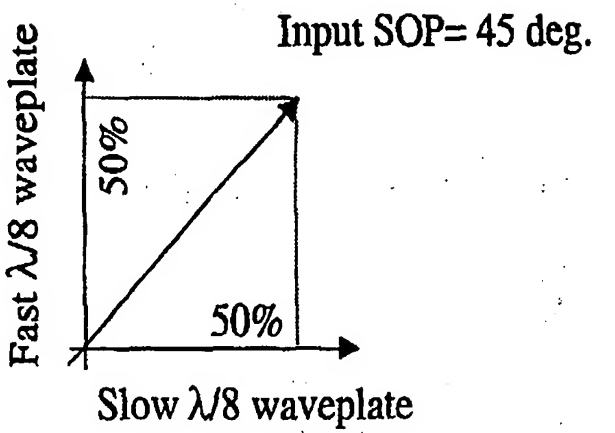
Polarization interferometer with a single birefringent GT

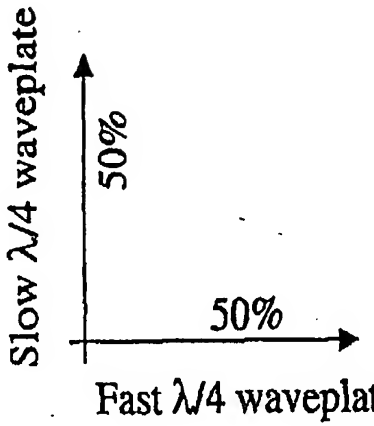
Example shown with input linearly polarized light

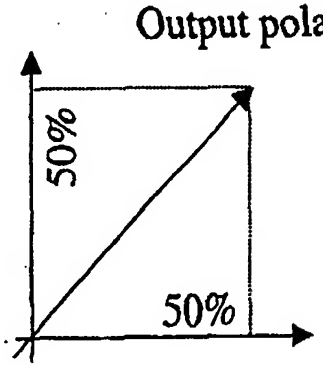


Reza's dual GT:

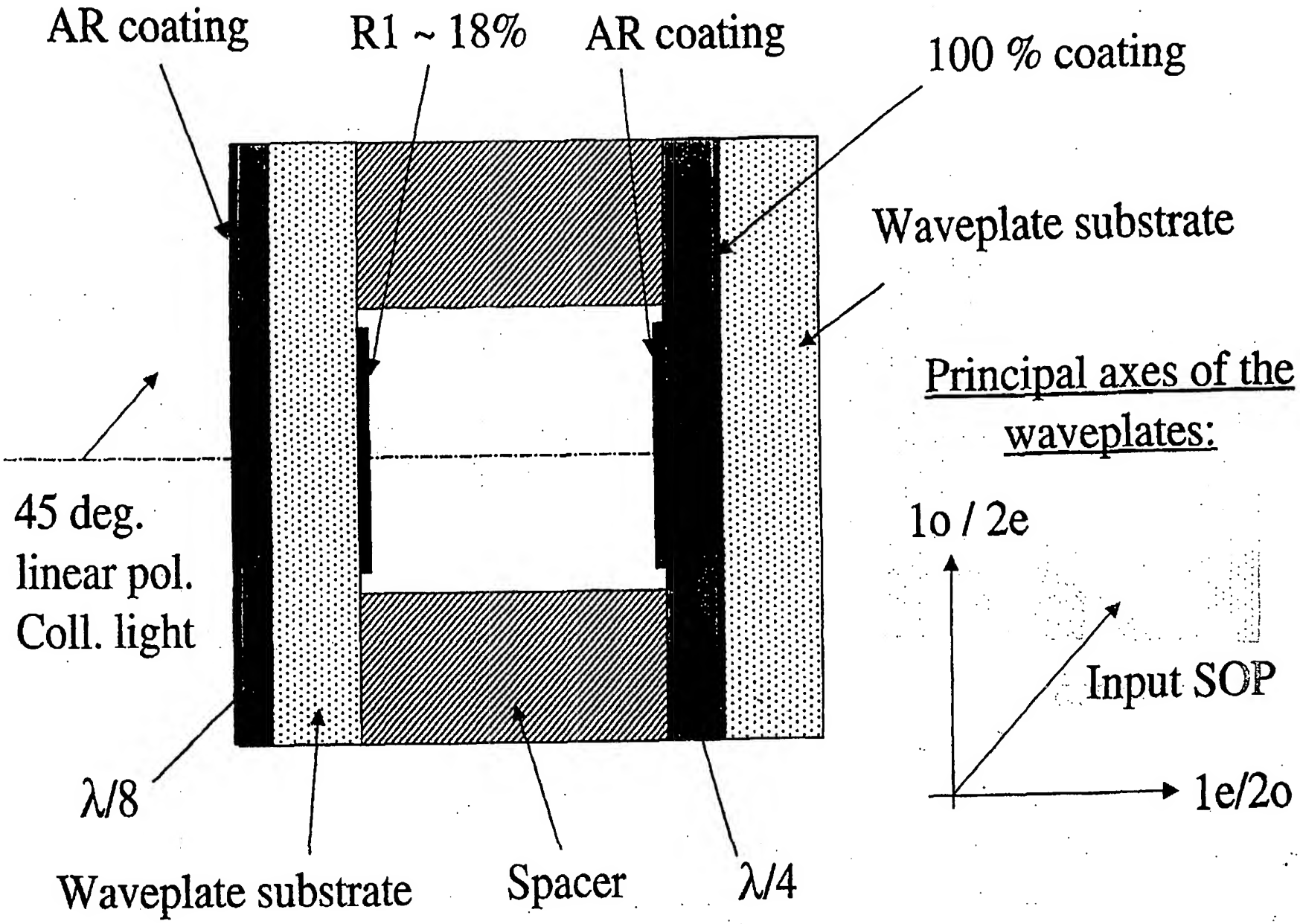
- 50/50 splitting
- λ/8 OPD
- λ/4 δFSR



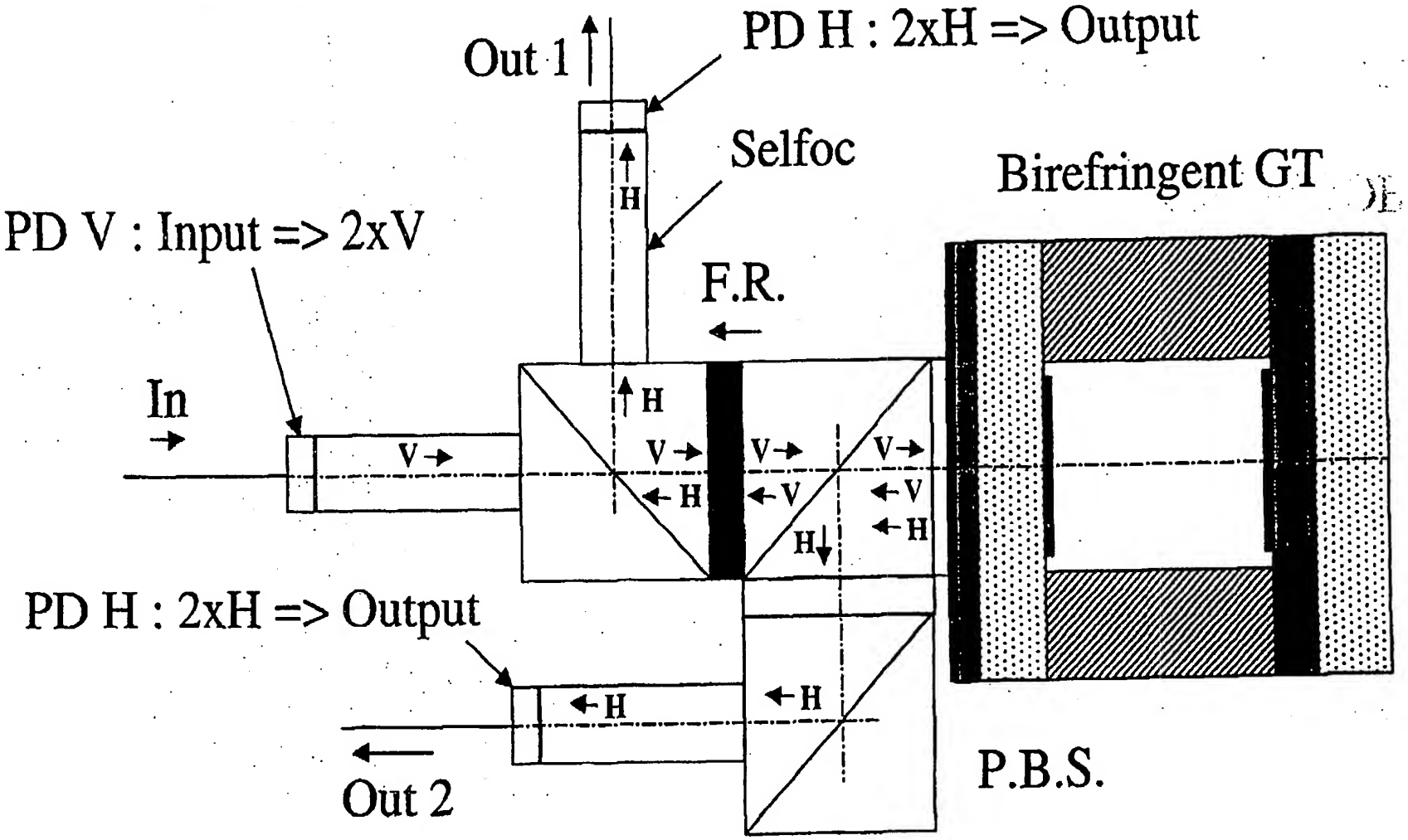




Proposed birefringent GT



Top view **ATHERMAL FLAT TOP INTERLEAVER (3 ports)**

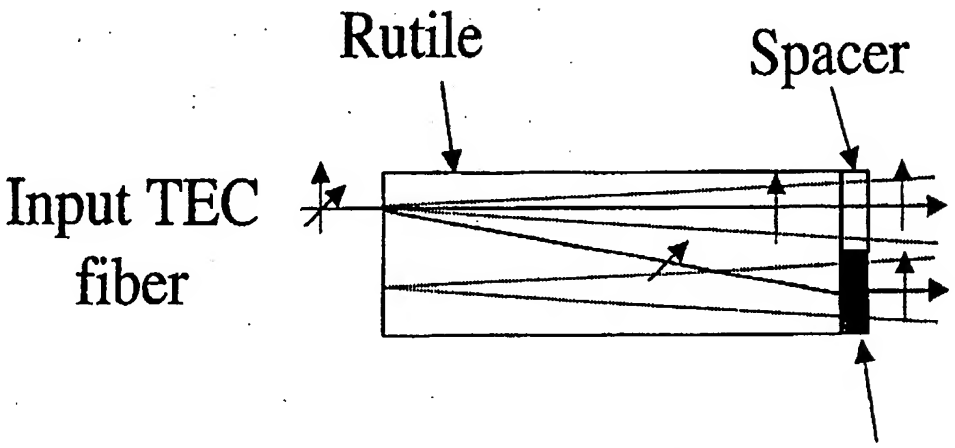


F.R. = Faraday Rotator / P.B.S. = Polarization Beam Splitter

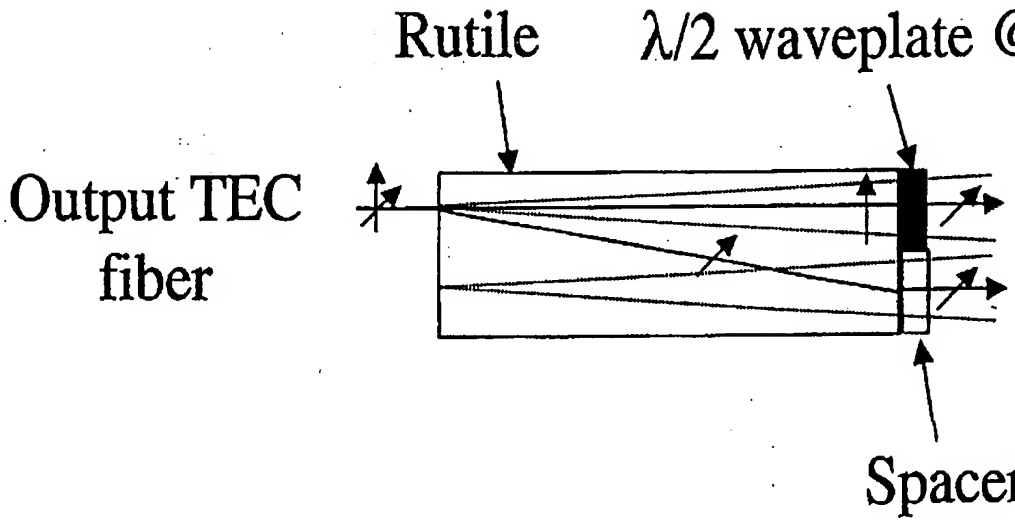
P.D. = Polarization diversity (rutile + λ/2 waveplates assembly)

Side view

ATHERMAL FLAT TOP INTERLEAVER (3 ports).

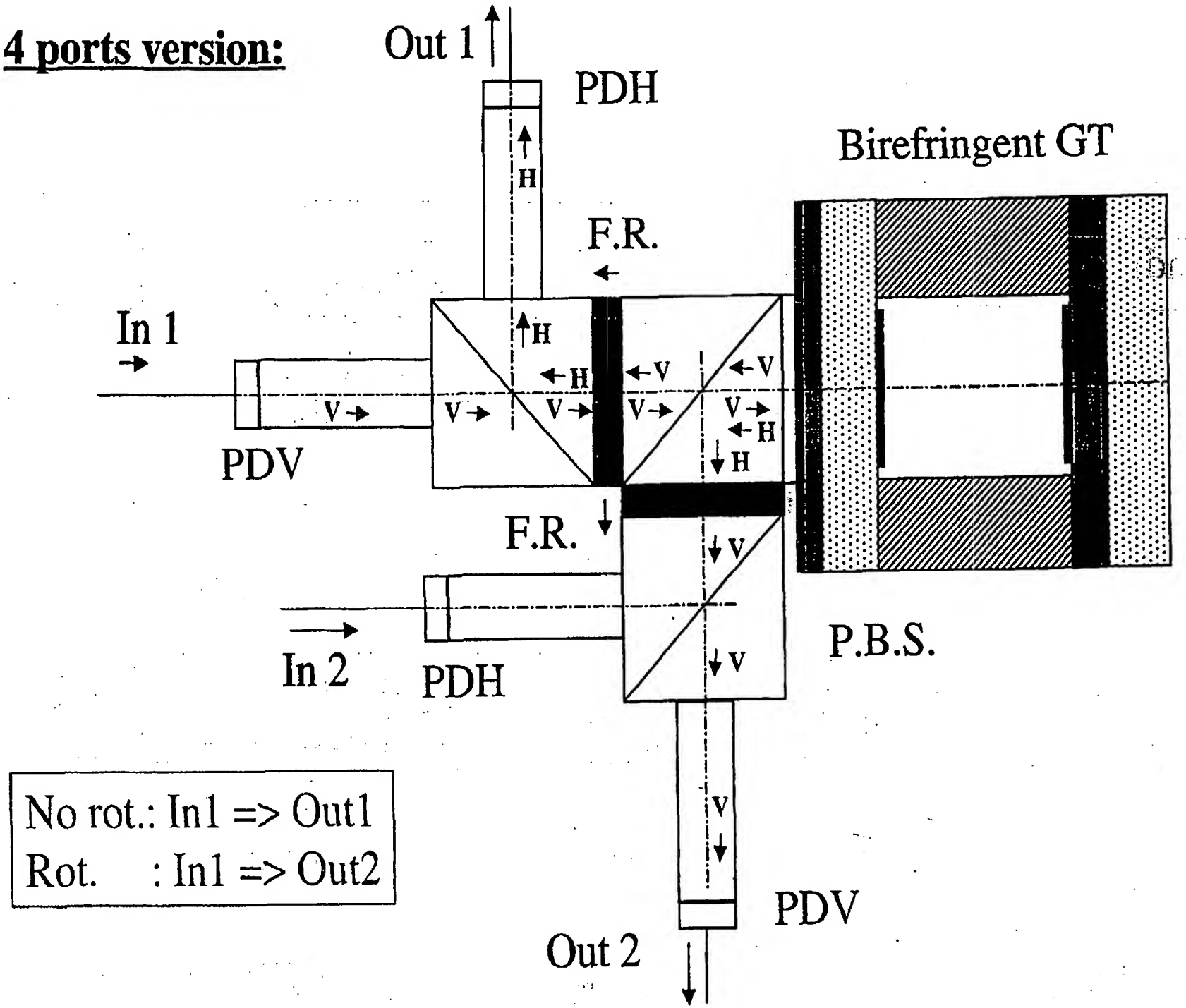


PD V : Input => 2xV



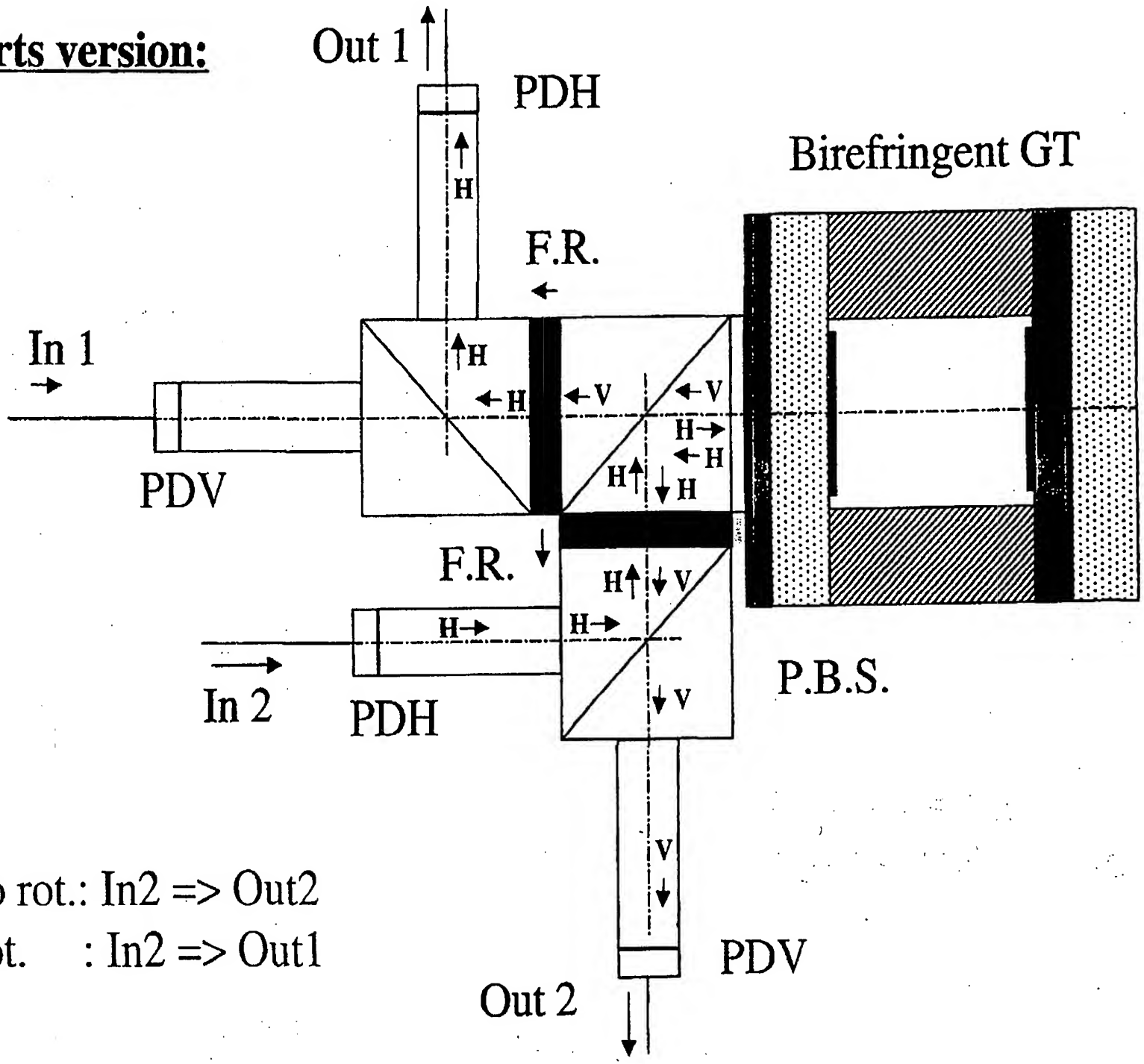
PD H : 2xH => Output

4 ports version:



No rot.: In1 => Out1
Rot. : In1 => Out2

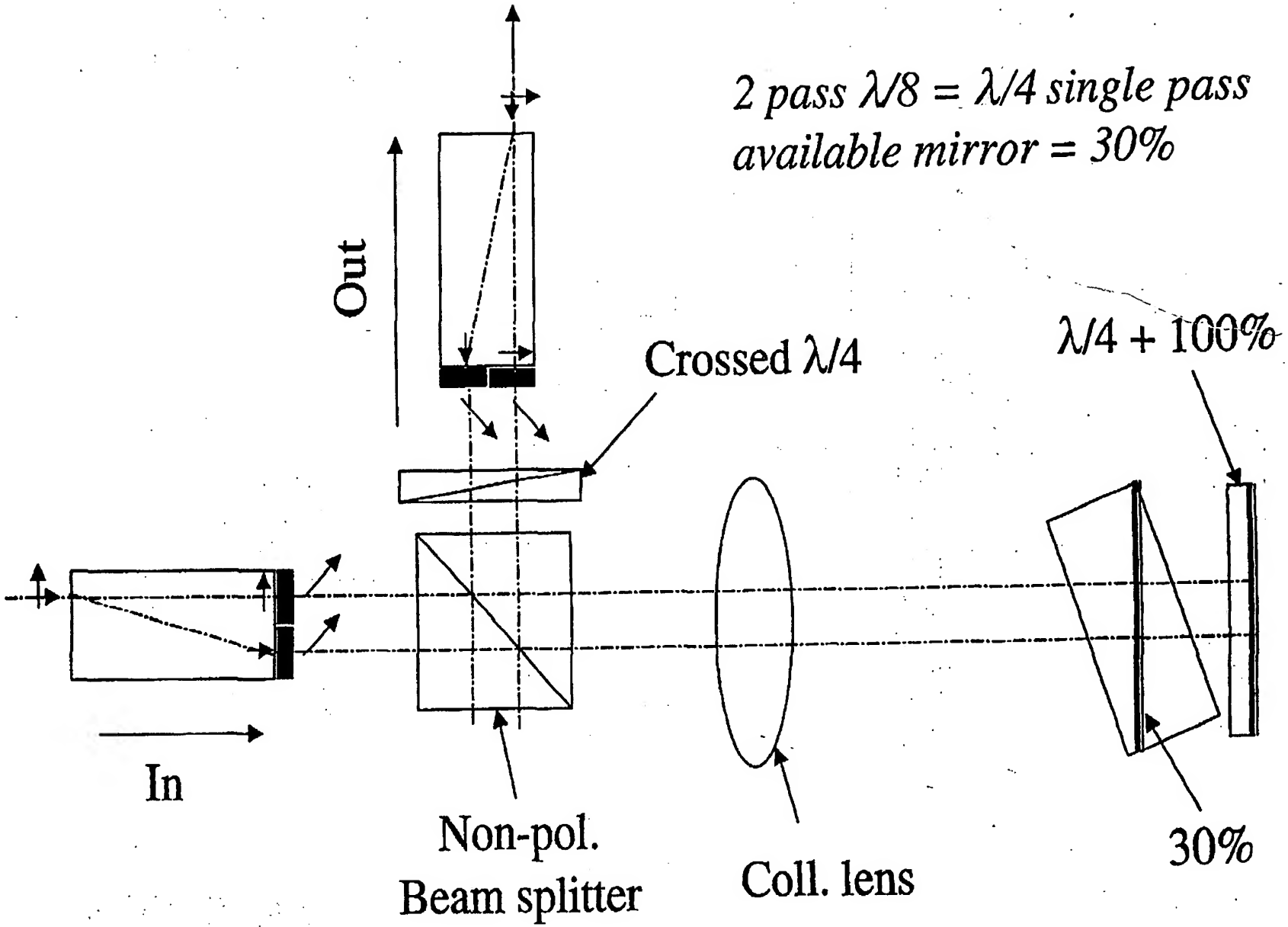
4 ports version:



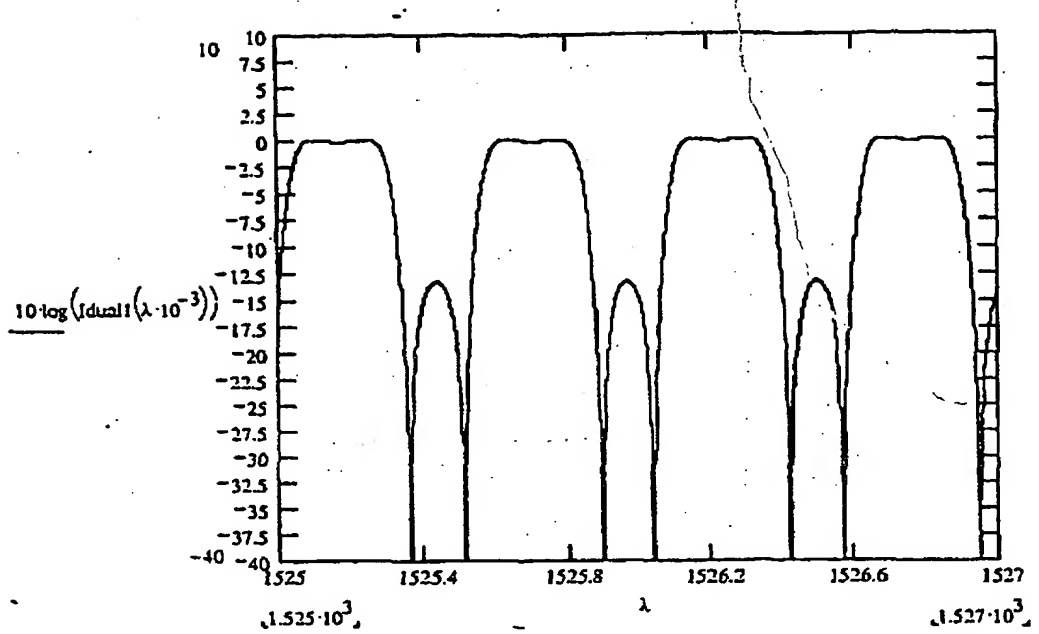
No rot.: In2 => Out2

Rot. : In2 => Out1

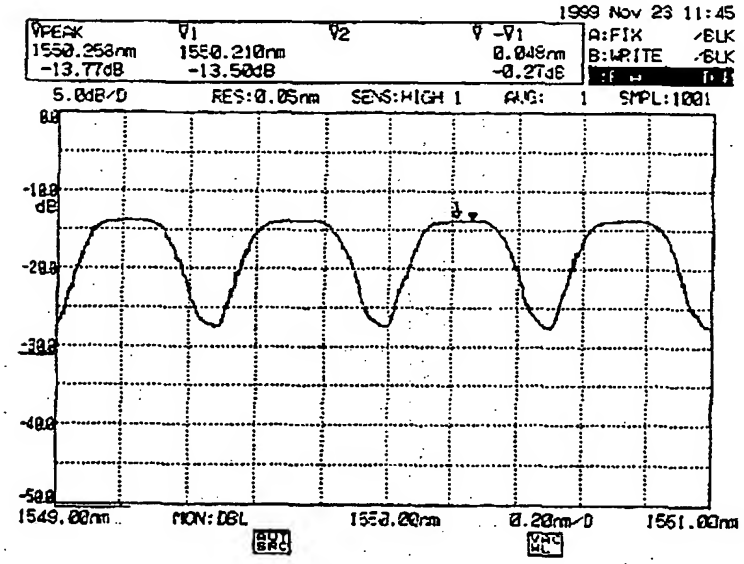
First Proof-of-concept on a bench:



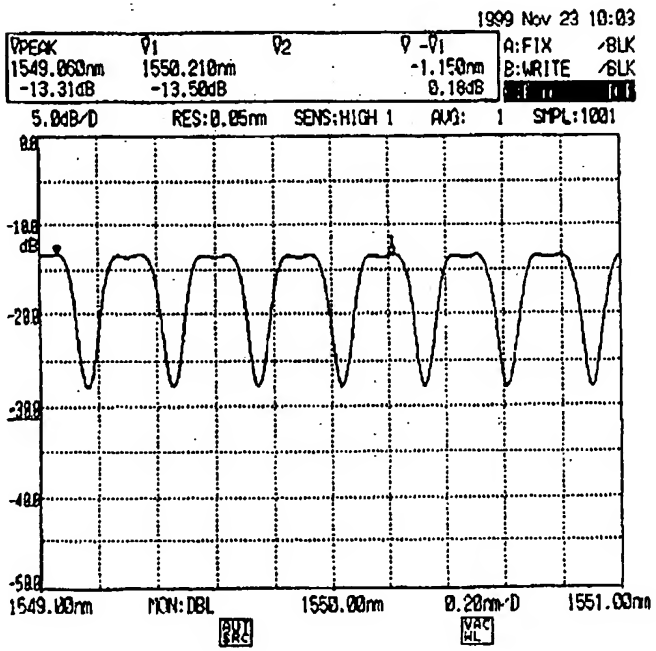
theory $R = 30\%$



Measurement



Measurement



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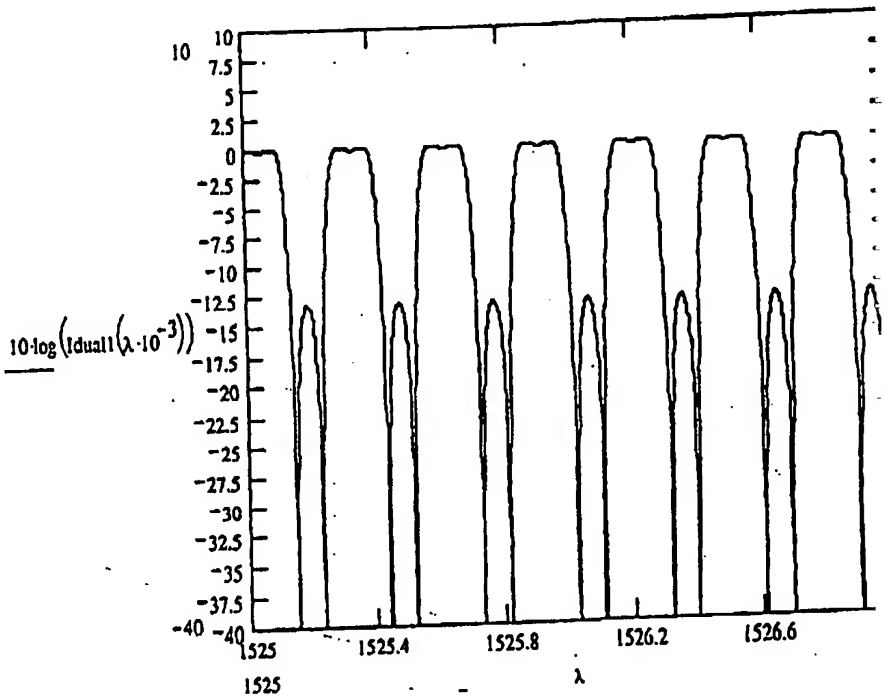

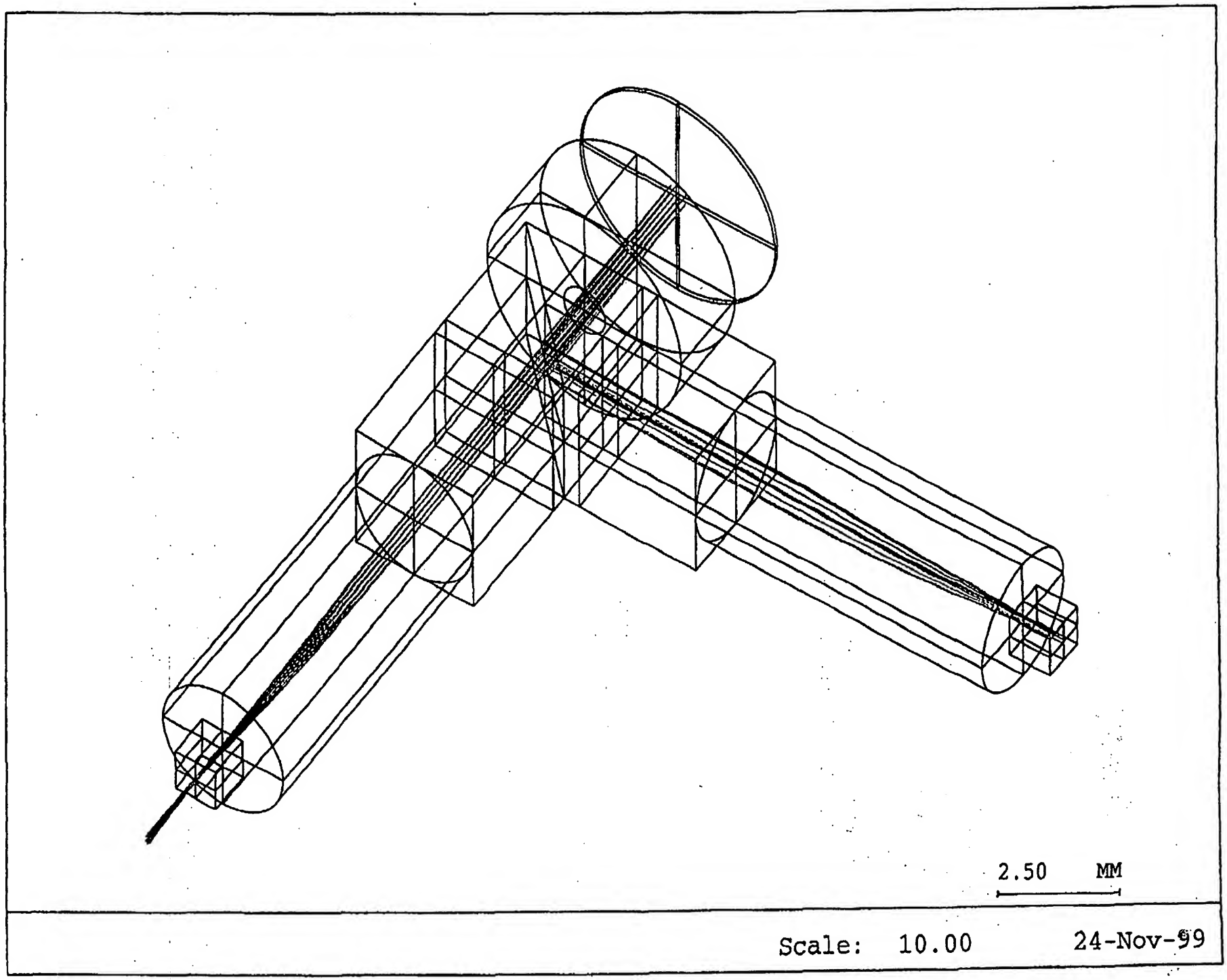
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